b. Mobile Earth Stations

The NGSO Satellite Services network also supports Mobile Earth Stations. The Mobile Earth Stations operate at multiple rates of the 16 kbps up to 2.048 Mbps (E1). The operation of the Mobile Earth Stations are similar to the Standard Earth Stations with following exceptions:
- The Mobile Earth Station can use a smaller antenna.
- The bandwidth for MSS is 100 MHz which can accommodate up to 360 basic channels in each cell.

The antenna patterns for the Mobile Standard Terminal and the Satellite Mobile Links are the same as the Satellite Standard Links as shown in Figures 2.8, 2.9 and 2.6.

c. High Rate Earth Station

The NGSO Satellite Service network also supports a smaller number of fixed-site High Rate Earth Stations that operate at the OC-3 rate (155.52 Mbps) and multiples of this rate up to OC-24 (1.24416 Gbps). Each satellite can support up to sixteen High Rate Earth Stations within its service area. Figures 2.10 and 2.11 show the antenna patterns of the High Rate Earth Station and Figure 2.7 shows the contour of the satellite antenna footprint for the Satellite High Rate Link.

3.0 Interference Analysis

In order to calculate the complex, time-varying interference statistics between the GSO FSS and the NGSO Satellite Service links, a detailed computer simulation program has been developed. The simulation program is based on software modules that have been previously developed and tested. The results of the simulation runs were validated by simple analysis and by comparison to another independently developed simplified simulation program.

The simulation program includes the satellite orbital ephemeris and visibility characteristics as viewed from any given location on the earth. It allows for a wide range of choices in specifying the NGSO orbital parameters, link parameters, and simulation duration and step size. The output of the simulation program at each step size is the Carrier-to-Interference power ratio at the interfered with receiver as given by:

$$C/I = P_T^C + G_T^C(0) - PL^C - G_R^C(0) - 10 \cdot \log \sum_{\text{for all I}} 10^{P_T^I + G_T^I(\theta_{I/C}) - PL^{I/C} + G_R^C(\theta_{C/I}) - BWF^{I/C}}$$

where

P_T^C is the desired signal transmit power (dBW)

$G_T^C(0)$ is desired signal transmit antenna peak gain (dB)

PL^C is the path loss from the desired transmitter to the receiver (dB)

$G_R^C(0)$ is the receiver antenna peak gain (dB)

P_T^I is the interference signal transmit power (dBW)

$G_T^C(\theta_{I/C})$ is the interference signal transmit antenna gain in the direction of the receiver (dB)

$PL^{I/C}$ is the path loss from the interfering transmitter to the receiver (dB)

$G_R^C(\theta_{C/I})$ is the receiver antenna gain in the direction of the interfering transmitter (dB)

$BWF^{I/C}$ is a bandwidth factor equal to 0 dB if the interference signal transmit bandwidth is less than or equal to the desired receive bandwidth and it is equal to 10 Log_{10} ($BW_{transmit}$ / $BW_{receive}$) if the interference signal transmit bandwidth is greater than the desired signal receive bandwidth.

There are four possible interference cases. In each of these cases the interference statistics between the GSO FSS and the three service links of the NGSO Satellite Service network are calculated. Figure 3.1 depicts the ground segment model that was used in the simulation . A grid of 5 by 5 or a total of 25 GSO FSS Earth Stations, each separated by 640 km, along with a grid of 21 by 21 or a total of 441 NGSO Satellite Standard Earth Stations or Mobile Earth Stations are considered. It is assumed that one NGSO earth station is co-located with a GSO FSS Earth Station. Furthermore it is assumed that in other cells that are separated by 160 km there are other NGSO Satellite Earth Stations communicating with the NGSO satellite. Figure 3.2 depicts the distribution of nine High Rate Earth Stations with one of them co-located with a GSO FSS Earth Station.

In what follows each of the interference cases are described and the method used in calculating the interference statistics is outlined.

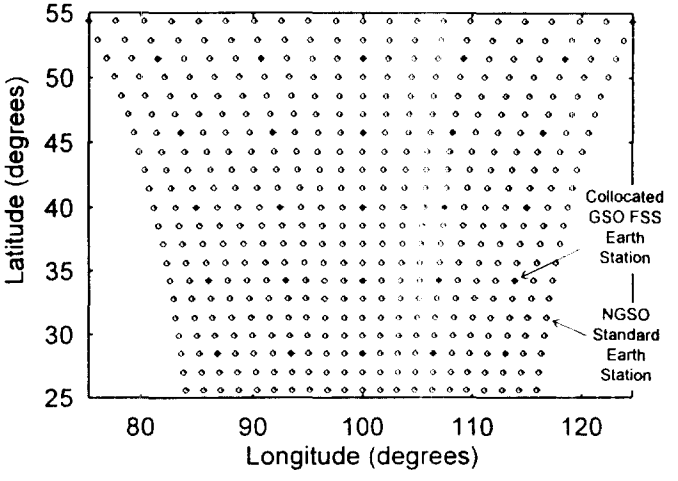

Figure 3.1: Ground Segment Distribution of NGSO Standard Earth Terminals.

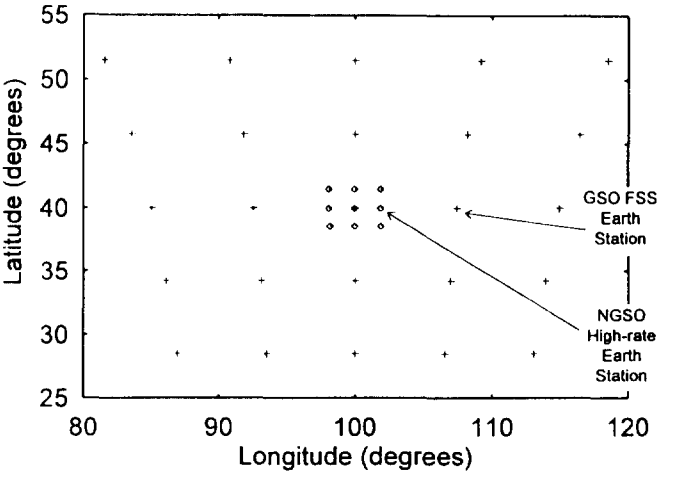

Figure 3.2: Ground Segment Distribution of NGSO High-rate Earth Terminals.

Case 1 : Interference from a NGSO Satellite into a GSO FSS Earth Station

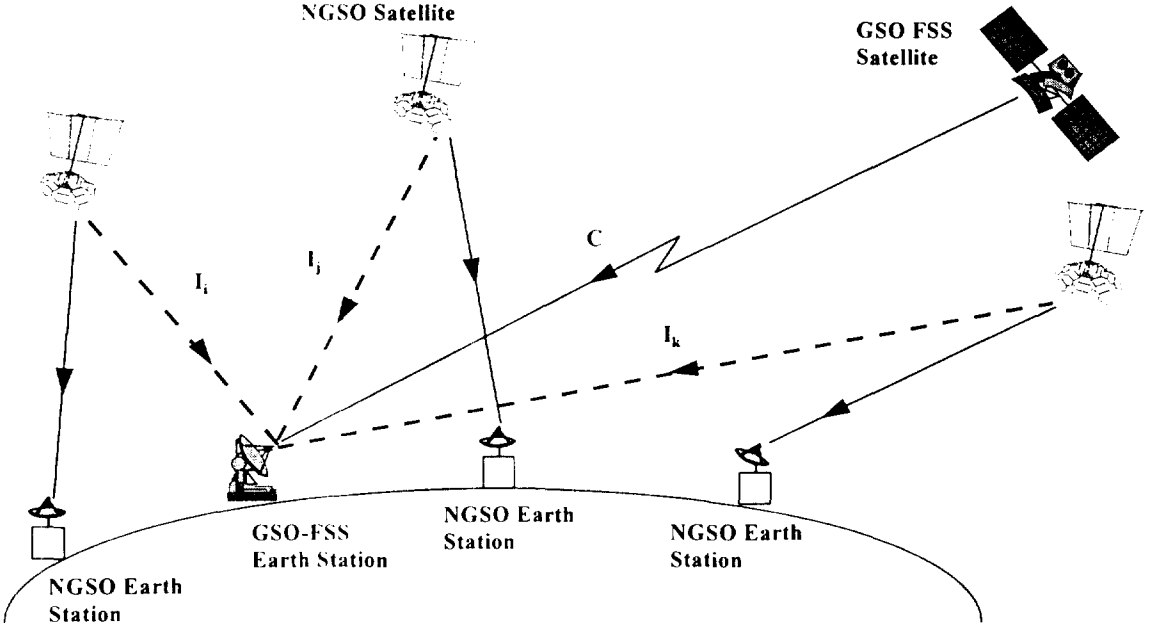

Figure 3.3 Case 1: Interference from NGSO Satellite into GSO FSS Earth Station.

This case is shown in figure 3.3. At each simulation step the carrier to interference power ratio at a GSO FSS Earth Station that is co-located with a NGSO Satellite Standard or Mobile Earth Station is calculated. The collocated earth stations are assumed to be located at the latitude of 40°N and longitude of

100°W. Additional simulations were also performed to evaluate the sensitivity of the interference statistics to the location of the collocated earth stations. The GSO FSS system does not employ power control for downlink. The interference power at the GSO FSS earth station is calculated by summing the interference power received from all the NGSO satellites communicating with their corresponding earth stations. For each NGSO Earth Station the corresponding NSGO satellite that is closest to it which has elevation angle of at least 40° is found and the interference power from that satellite to the GSO FSS Earth Station is calculated. The antenna discrimination from the NGSO satellite antenna is found by calculating the distance between the GSO FSS Earth Station and the NGSO Earth Station communicating with that satellite.

Parameter	Desired	NGSO Interference			Units
	GSO FSS Link	Standard Link (T1)	Mobile Link (T1)	OC24 High Rate Link	
+ Transmit Power	13.0	18.8	18.8	-1.2	dBW
- Transmit Losses	0.5	2.0	2.0	0.5	dB
+ Transmit Ant. Peak Gain	46.5	32.0	32.0	41.0	dBi
= Transmitted EIRP	59.0	48.8	48.8	39.3	dBW
- Free Space Loss	209.6	177.6	177.6	177.6	dB
- Atmospheric Losses	1.1	1.0	1.0	1.0	dB
+ Receiving Ant. Peak Gain	43.1	43.1	43.1	43.1	dBi
= Received Carrier Power	-108.6				dBW
= Received Interference Power		-86.7	-86.7	-96.2	dBW
- LEO SAT-1 Transmit BW		86.0	80.0	89.0	dB-Hz
+ GSO 13 Transmit BW		80.8	80.8	80.8	dB-Hz
= In-Band Interference Power		-91.9	-86.7	-104.4	dBW
Thermal Noise Power	-123.3				dBW
C/N at GSO 13 Earth Station	14.7				dB
Eb/No at GSO 13 Earth Station	15.8				dB
C/I at GSO 13 Earth Station		-16.7	-21.9	-4.2	dB
C/I Required (Protection Ratio)	18.2				dB

Table 3.1 Interference Link Budget for Case 1: Interference from NGSO Satellite into GSO FSS Earth Station.

An example interference link budget is given in Table 3.1. In this example, a single NGSO earth station (standard terminal, mobile terminal and high rate terminal) collocated with the GSO FSS Earth station is considered. The interference power is computed from a single NGSO satellite-to-earth station link when the satellites are "in-line" at 43.7° elevation from the point of view of the GSO FSS Earth Station

Case 2: Interference from NGSO Earth Station into a GSO FSS Satellite

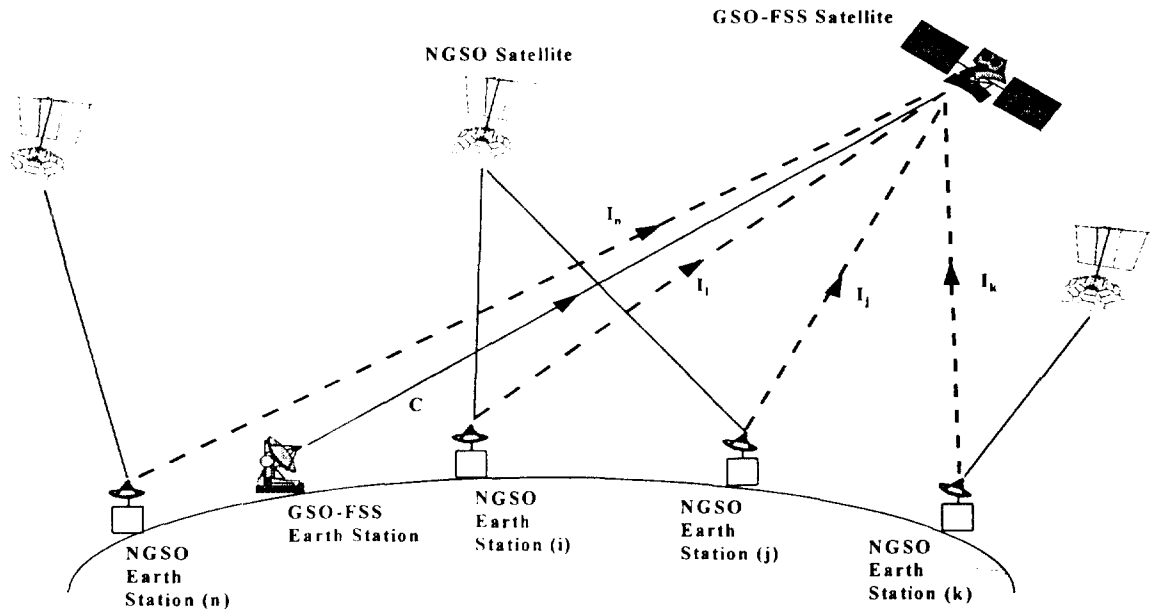

Figure 3.4 Case 2: Interference from NGSO Earth Station into GSO FSS Satellite.

Parameter	Desired	NGSO Interference			Units
	GSO FSS Link	Standard Link (T1)	Mobile Link (T1)	OC24 High Rate Link	
+ Transmit Power	-9.7	-2.1	3.9	-1.9	dBW
- Transmit Losses	0.5	0.5	0.5	0.5	dB
+ Transmit Ant. Peak Gain	44.4	36.0	30.0	50.0	dBi
= Transmitted EIRP	34.2	33.4	33.4	47.6	dBW
- Free Space Loss	213.1	213.1	213.1	213.1	dB
- Atmospheric Loss	1.0	1.0	1.0	1.0	dB
+ Receiving Ant. Peak Gain	46.5	46.5	46.5	46.5	dBi
= Received Carrier Power	-133.4				dBW
= Received Interference Power		-134.2	-134.2	-120.0	dBW
- LEO SAT-1 Transmit BW		74.2	74.2	89.0	dB-Hz
+ GSO 13 Transmit BW		57.0	57.0	57.0	dB-Hz
= In-Band Interference Power		-151.4	-151.4	-152.0	dBW
Thermal Noise Power	-144.0				dBW
C/N at GSO 13 Satellite	10.6				dB
Eb/No at GSO 13 Satellite	11.7				dB
C/I at GSO 13 Satellite		18.0	18.0	18.6	dB
C/I Required (Protection Ratio)	18.2				dB

Table 3.2 Interference Link Budget for Case 2: Interference from a NGSO Satellite Earth Station into a GSO FSS Satellite.

This case is shown in figure 3.4. The simulation procedure for this case is the same as that of case one with the exception that this case deals with the interference into the GSO FSS Satellite. The GSO FSS System employs power control for uplink to compensate for slant range to achieve a desired Carrier-to-Noise Power ratio at the GSO FSS Satellite of 10 dB. The sum of the interference power from all the NGSO Earth Stations is calculated in this case.

An example interference link budget is given in Table 3.2. In this example, a single NGSO Earth Station (Standard terminal, Mobile terminal and High Rate terminal) collocated with a GSO FSS Earth station is considered. The interference power is computed from the single ground-to-satellite link when the satellites are "in-line" at 43.6° elevation from the point of view of the GSO FSS earth station.

Case 3: Interference from GSO FSS Earth Stations into NGSO Satellite

This case is shown in figure 3.5. At each simulation step the carrier to interference power ratio at the NGSO Satellite is calculated. It is assumed that the NGSO Earth Station that is communicating with the NGSO satellite is collocated with a GSO FSS Earth Station. The NGSO Satellite System employs power control for uplink to maintain a carrier to noise power ratio of 7.6 dB for the Standard and Mobile Links and 12.0 dB for the High Rate links. The aggregate interference power received at the NGSO Satellite from all 25 GSO FSS Earth Stations is calculated at each simulation step.

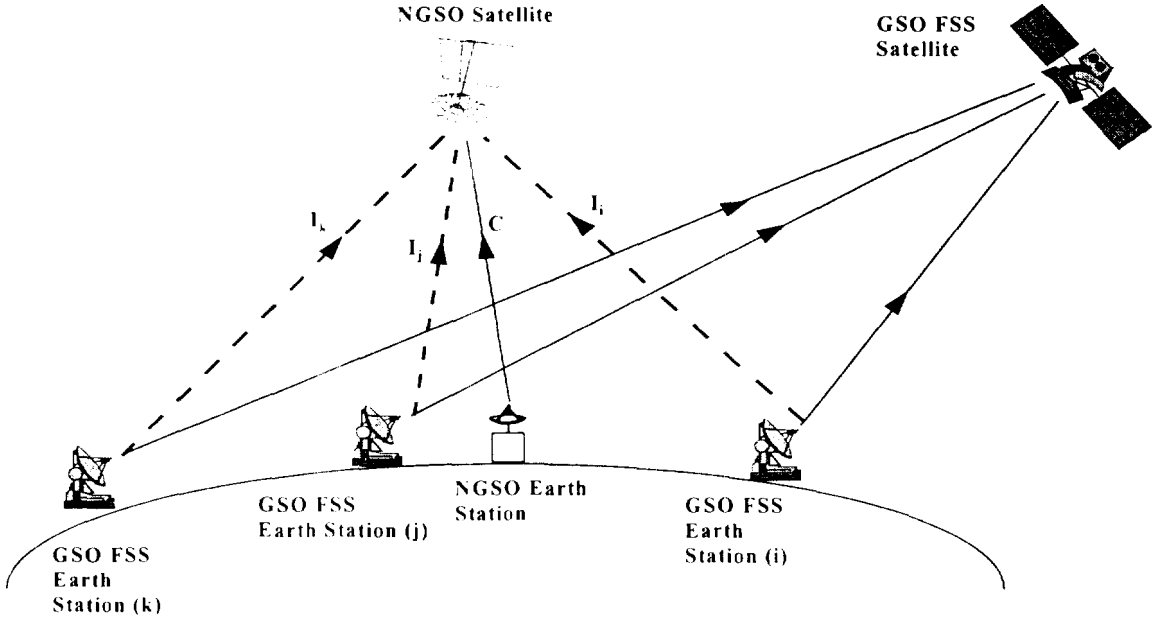

Figure 3.5 Case 3: Interference from GSO FSS Earth Station into NGSO Satellite

An example interference link budget is given in Table 3.3. In this example the GSO FSS Earth Station is assumed to be collocated with the NGSO Earth Station (Standard terminal, Mobile terminal and High Rate terminal). The satellites of both systems are "in-line" at 43.6° elevation from the point of view of the NGSO Earth Station.

Parameter	Desired			Interference	Units
	Standard Link (16K)	Mobile Link (16K)	OC24 High Rate Link	GSO FSS Link	
+ Transmit Power	-21.9	-15.9	-1.9	-9.7	dBW
- Transmit Losses	0.5	0.5	0.5	0.5	dB
+ Transmit Ant. Peak Gain	36.0	30.0	50.0	44.4	dBi
= Transmitted EIRP	13.6	13.6	47.6	34.2	dBW
- Free Space Loss	181.3	181.3	181.3	181.3	dB
- Atmospheric Loss	1.0	1.0	1.0	1.0	dB
+ Receiving Ant. Peak Gain	32.0	32.0	41.0		dBi
= Received Carrier Power	-136.7	-136.7	-93.7		dBW
= Received Interference Power	-116.1	-116.1	-107.1		dBW
- GSO 13 Transmit BW	57.0	57.0	57.0		dB-Hz
+ LEO SAT-1 Transmit BW	54.4	54.4	89.0		dB-Hz
= In-Band Interference Power	-118.7	-118.7	-107.1		dBW
C/N at LEO SAT-1 Satellite	9.2	9.2	17.6		dB
C/I at LEO SAT-1 Satellite	-18.0	-18.0	13.4		dB
C/I Required (Protection Ratio)	25.0	25.0	25.0		dB

Table 3-3 Interference Link Budget For Case 3: Interference from GSO FSS Earth Station into NGSO Satellite.

Case 4: Interference from GSO FSS Satellite into NGSO Earth Station

This case is shown in figure 3.6. At each simulation step the carrier to interference ratio at the NGSO Satellite Earth Station is calculated. The NGSO Satellite System does not employ power control on the downlinks. The aggregate interference power received at that NGSO Satellite Earth Station from the GSO FSS Satellite communicating with all 25 GSO FSS Earth Stations is considered.

An example interference link budget is given in Table 3.4. In this example, the interferer, GSO FSS Satellite is transmitting to a GSO FSS Earth Station that is collocated with the NGSO Earth Station (Standard terminal, Mobile terminal and High Rate terminal). Satellites of both systems are "in-line" at 43.6° elevation angle from the point of view of the NGSO Earth Station.

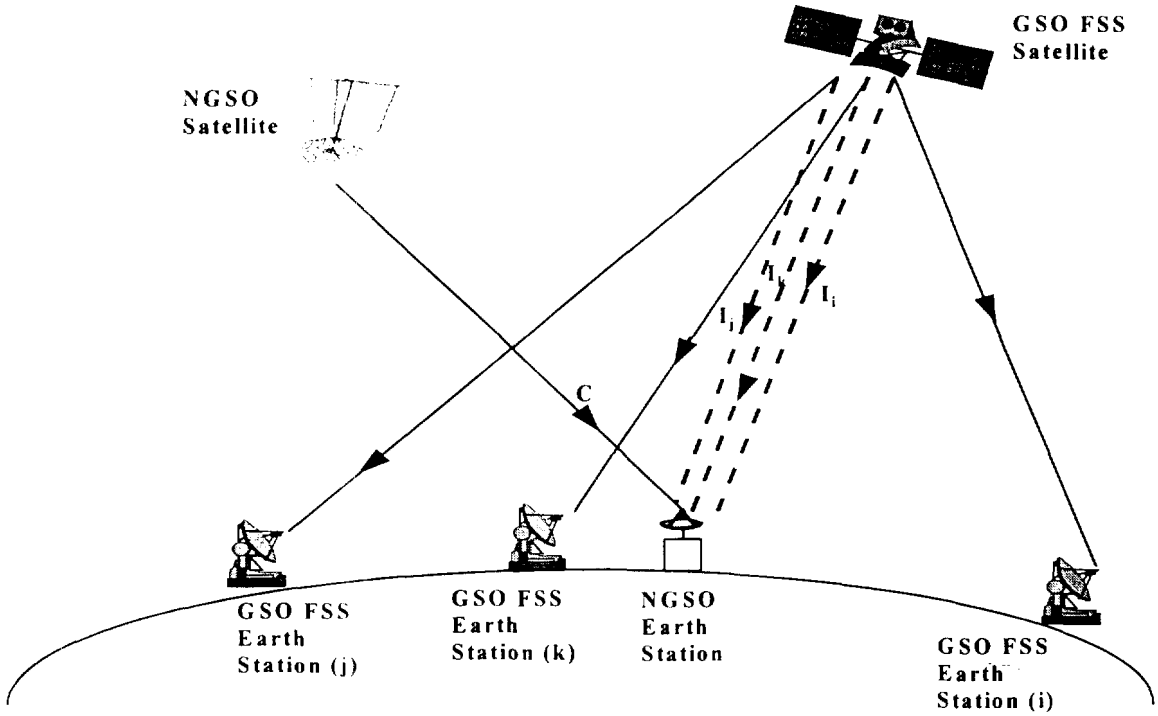

Figure 3.6 Case 4: Interference from GSO FSS Satellite into NGSO Earth Station

Parameter	Desired			Interference	Units
	Standard Link(16K)	Mobile Link(16K)	OC24 High Rate Link	GSO FSS Link	
+ Transmit Power	18.8	18.8	-1.2	13.0	dBW
- Transmit Losses	2.0	2.0	0.5	0.5	dB
+ Transmit Ant. Peak Gain	32.0	32.0	41.0	46.5	dBi
= Transmitted EIRP	48.8	48.8	39.3	59.0	dBW
- Free Space Loss	177.6	177.6	177.6	209.6	dB
- Atmospheric Loss	1.0	1.0	1.0	1.0	dB
+ Receiving Ant. Peak Gain	33.0	27.0	47.0		dBi
= Received Carrier Power	-96.8	-102.8	-92.3		dBW
= Received Interference Power	-118.6	-124.6	-104.6		dBW
- GSO 13 Transmit BW	80.8	80.8	80.8		dB-Hz
+ LEO SAT-1 Transmit BW	86.0	80.0	89.0		dB-Hz
= In-Band Interference Power	-118.6	-125.4	-104.6		dBW
C/N at LEO SAT-1 Earth Station	19.2	19.2	21.5		dB
C/I at LEO SAT-1 Earth Station	21.8	22.6	12.3		dB
C/I Required (Protection Ratio)	25.0	25.0	25.0		dB

Table 3.4 Interference Link Budget For Case 4: Interference from GSO FSS Satellite into NGSO Satellite Earth Station.

4.0 Simulation Results

The simulation program described in the previous section has been used to calculate the interference statistics between the GSO FSS System, and the FSS and MSS service and feeder links of a NGSO Satellite System. The output of the simulation program is the time history of the C/I at each simulation step. In order to gain additional insight and understanding of the simulation results, a post processor program has been developed that calculates and plots the following statistics:

a) C/I time history
b) C/I probability density function and cumulative probability distribution function
c) Interference event duration statistics
d) Interval between interference events statistics

The interference between the GSO FSS and three different NGSO Satellite System links are considered.

a) NGSO Standard Links - Figures 4.1 to 4.8 show the interference statistics from NGSO satellite standard link into the GSO FSS Earth Station. Probability of interference in this case increases from 5.4% for the case with collocated earth stations at latitude 40° to 11.9% for collocated earth stations at latitude 25°. Figures 4.9 to 4.12 show the interference statistics for case 2. The interference in this case is not very severe. Figures 4.13 to 4.20 show the case 3 interference statistics for standard links. The interference probability in this case is very severe and its value changes between 15.5% to 24.9% depending on the latitude of the earth stations. Finally Figures 4.21 to 4.24 show the interference statistics for case 4.

b) NGSO Mobile Links - Figures 4.25 to 4.32 show the case 1 interference statistics for NGSO Mobile Links. In this case the interference for mobile links is more severe than the standard links. This due to higher power flux density that is transmitted by the NGSO satellite. The interference statistics of mobile links for cases 2 and 3 are the same as standard links and the plots are repeated here. Due to the higher power flux density of the NGSO satellites for mobile links, the interference statistics of case 4 for mobile links are less severe than the standard links.

c) NGSO High Rate Links - The interference between the NGSO High Rate Links and the GSO FSS links are not very severe. In fact the only statistics that

are plotted in Figures 4.33 to 4.42 are for the case when the collocated earth stations are located at latitude 25°. The interference between NGSO High Rate Links and the GSO FSS Links can further be reduced by separating the earth stations of the two systems.

Table 4.1 summarizes the results of the simulation runs.

		NGSO Earth Station Collocated with the GSO Earth Station at Latitude 40°				NGSO Earth Station Collocated with the GSO Earth Station at Latitude 25°			
		Probability of Interference (%)	Mean Interference Event Duration (sec)	Maximum Interference Event Duration (sec)	Mean Time Between Events (minutes)	Probability of Interference (%)	Mean Interference Event Duration (sec)	Maximum Interference Event Duration (sec)	Mean Time Between Events (minutes)
Standard Earth Station Collocated	Case 1	5.4	14.2	44	4.21	11.9	39.9	52	5.0
	Case 2	< 0.001	[B]	[B]	[B]	0.13	2.3	4	36
	Case 3	15.5	26.7	64	2.46	24.9	50.6	74	2.6
	Case 4	< 0.001	[B]	[B]	[B]	0.27	6.3	10	38.7
Mobile Earth Station Collocated	Case 1	20.2	30.3	80	2.0	29.0	55.7	82	2.3
	Case 2	< 0.001	[B]	[B]	[B]	0.13	2.3	4	36
	Case 3	15.5	26.7	64	2.46	24.9	50.6	74	2.6
	Case 4	< 0.001	[B]	[B]	[B]	< 0.001	[B]	[B]	[B]
High rate Earth Station Collocated	Case 1	< 0.001	[B]	[B]	[B]	0.67	10.1	14	25.2
	Case 2	0.	0.	0.	0.	< 0.001	[B]	[B]	[B]
	Case 3	< 0.001	[B]	[B]	[B]	0.16	5.0	8	53.3
	Case 4	< 0.001	[B]	[B]	[B]	0.10	3.1	6	53.6
High rate Earth Station at 160 km	Case 1	0.	0.	0.	NA	0.	0.	0.	NA
	Case 2	0.	0.	0.	NA	0.	0.	0.	NA
	Case 3	0.	0.	0.	NA	0.	0.	0.	NA
	Case 4	< 0.001	[B]	[B]	[B]	0.06	[B]	[B]	[B]

Table 4.1

Note [B] : The number of interference events that occurred during the simulated period was too small to obtain reliable statistics.

5. Conclusion

This paper presents statistical results that are useful in evaluating the potential for frequency sharing. However, the exact criteria for frequency sharing between the GSO FSS System, and the FSS and MSS, Service and Feeder links of a NGSO Satellite System have not been defined.

The simulation results indicate a positive potential for sharing between the GSO FSS and the NGSO Satellite System High Rate Links (FSS Service Links and FSS and MSS Feeder Links) with site separation between the respective Earth Stations. Additional work is required to determine the minimum separation requirement based on the acceptable interference levels.

The interference levels between the GSO FSS System and the NGSO Satellite System Standard and Mobile Links are significantly higher. The interference levels change as a function of earth station latitudes. Additional work is required to determine the effect of mitigation techniques in improving the sharing potential.

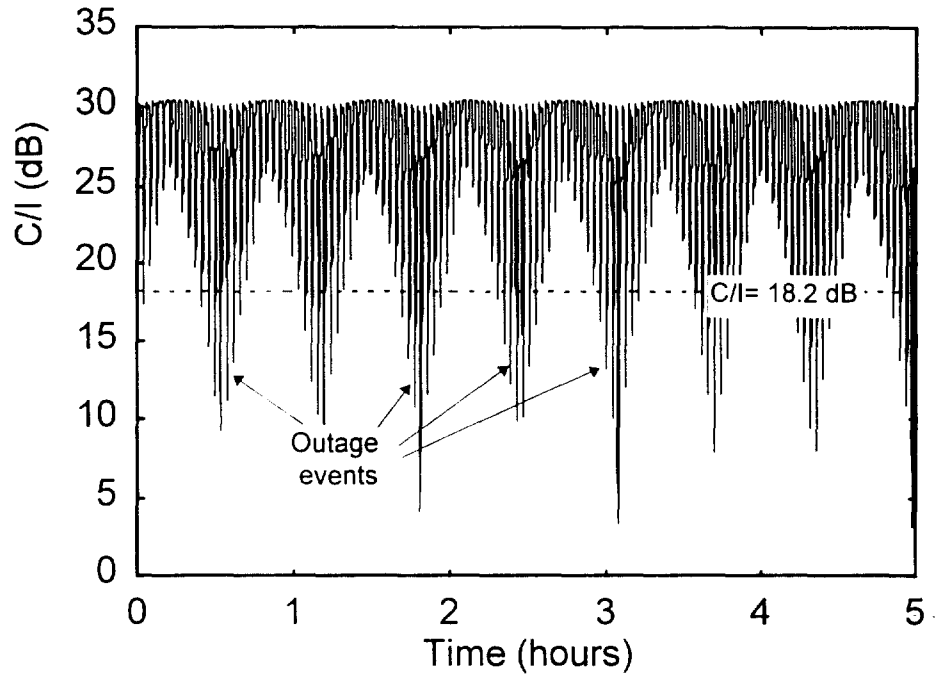

Figure 4.1 CASE 1, Latitude 40°, C/I Time History, Standard Earth Station .

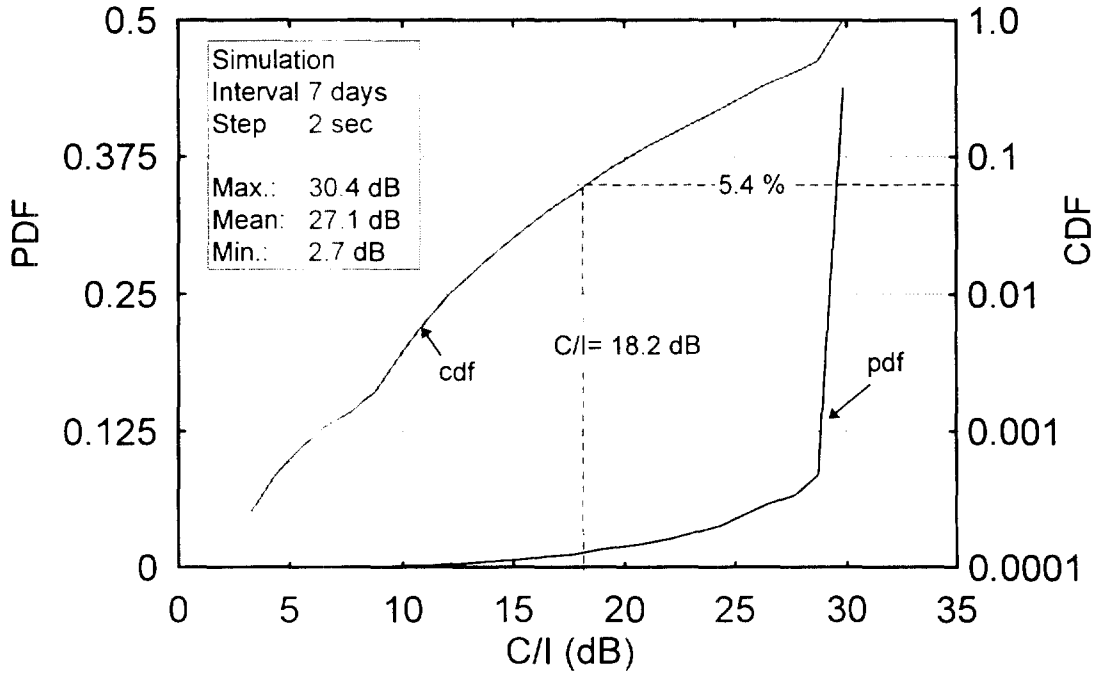

Figure 4.2 CASE 1, Latitude 40°, C/I Probability, Standard Earth Station .

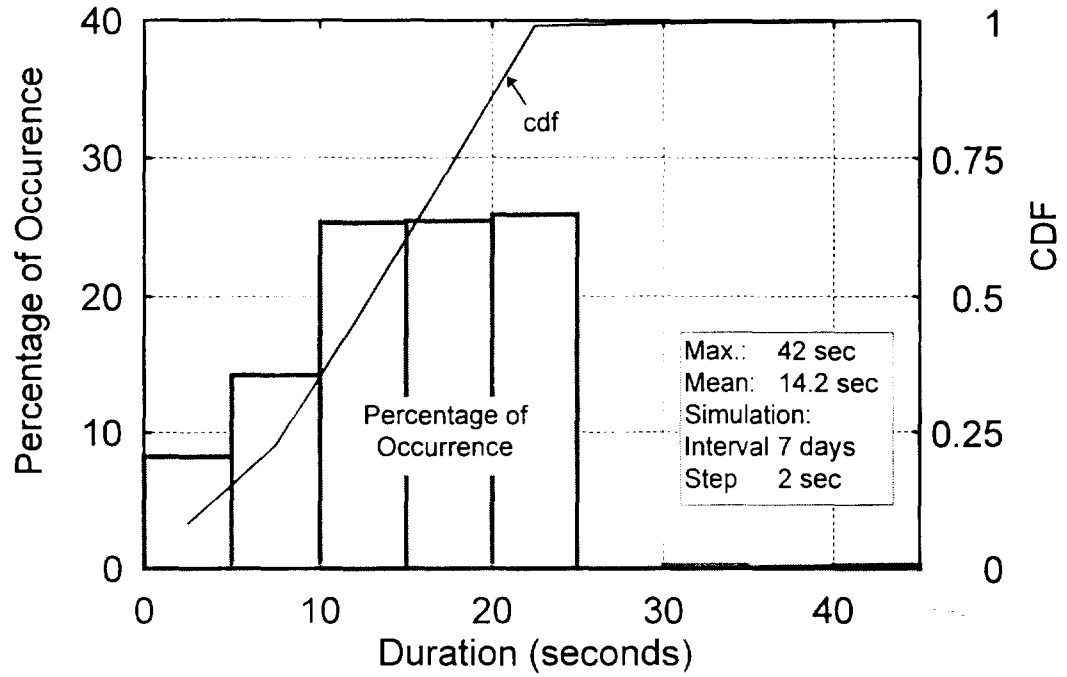

Figure 4.3 CASE 1, Latitude 40°, Interference Event Duration, Standard Earth Station .

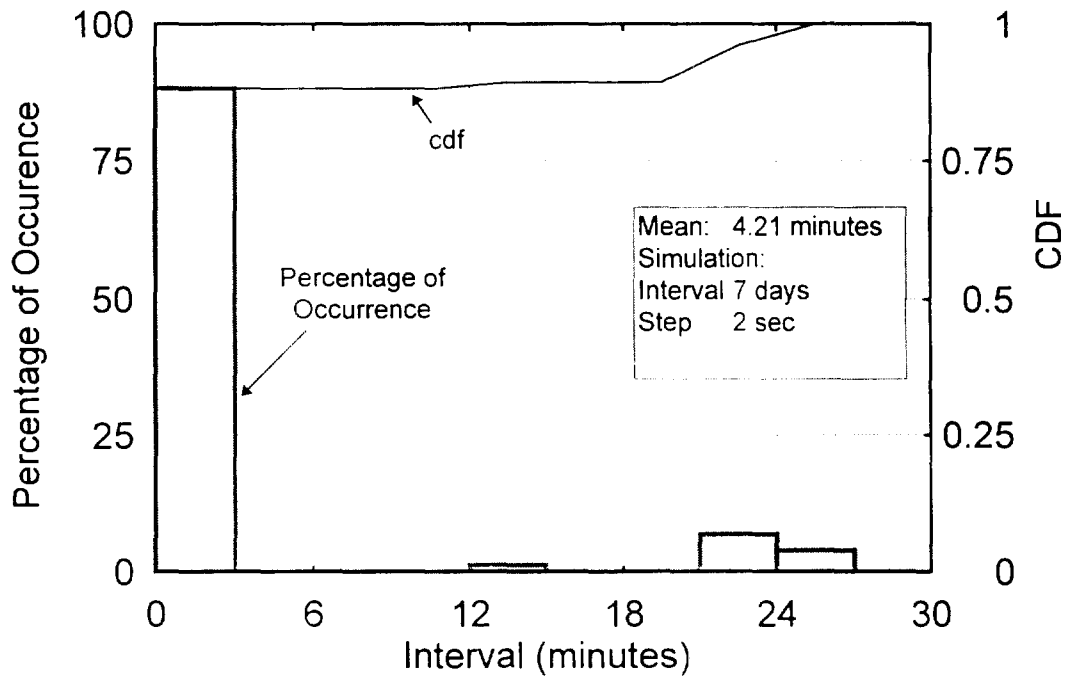

Figure 4.4 CASE 1, Latitude 40°, Interval Between Interference Events, Standard Earth Station .

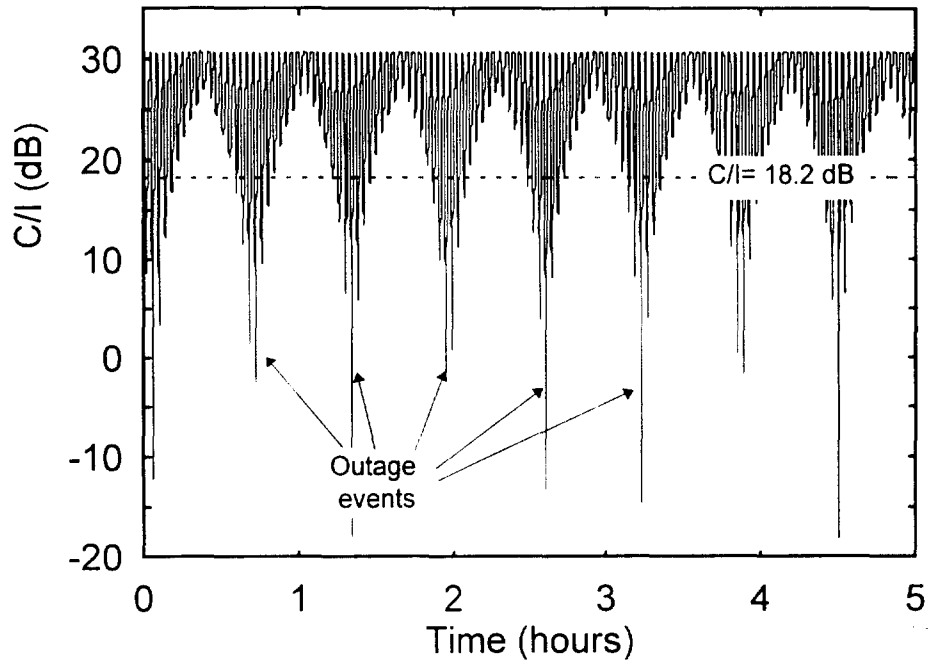

Figure 4.5 CASE 1, Latitude 25°, C/I Time History, Standard Earth Station .

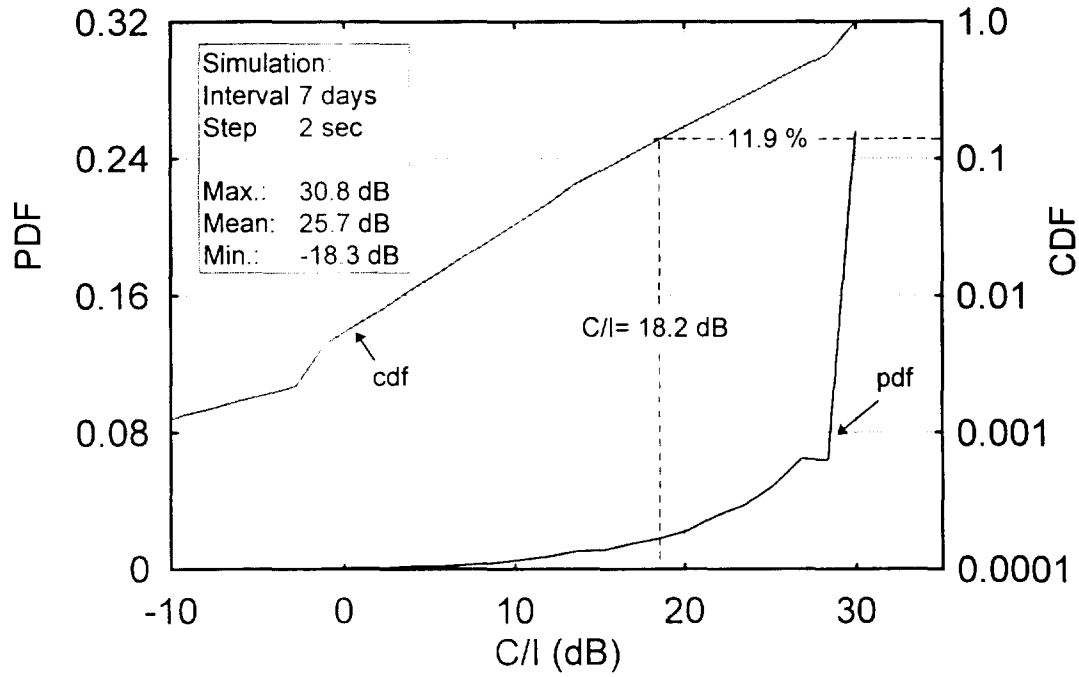

Figure 4.6 CASE 1, Latitude 25°, C/I Probability, Standard Earth Station .

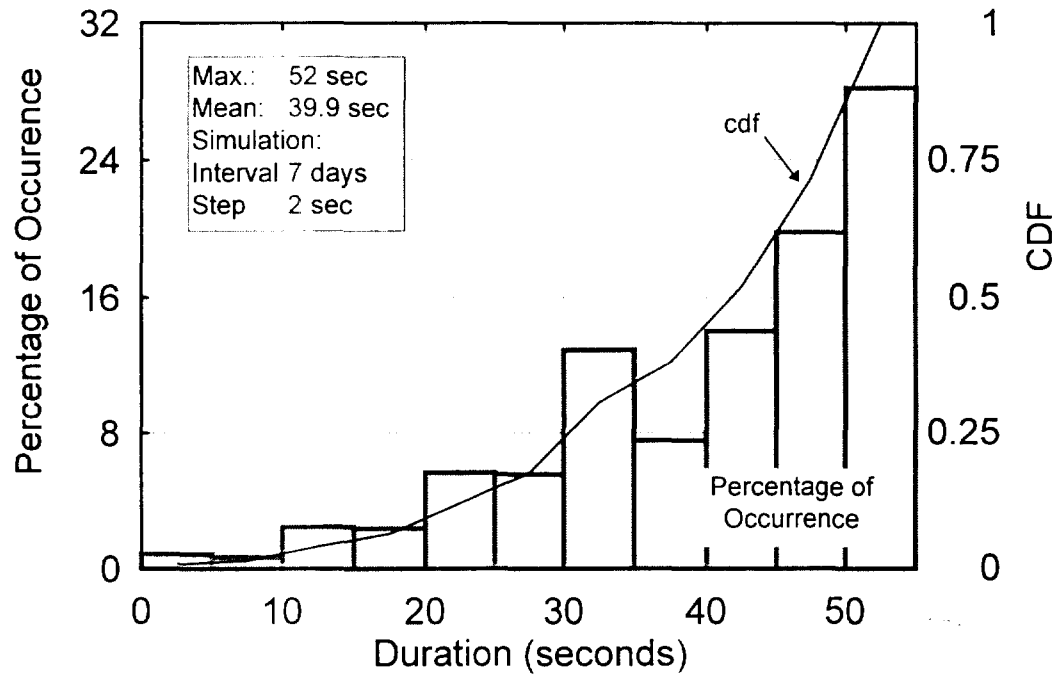

Figure 4.7 CASE 1, Latitude 25°, Interference Event Duration, Standard Earth Station .

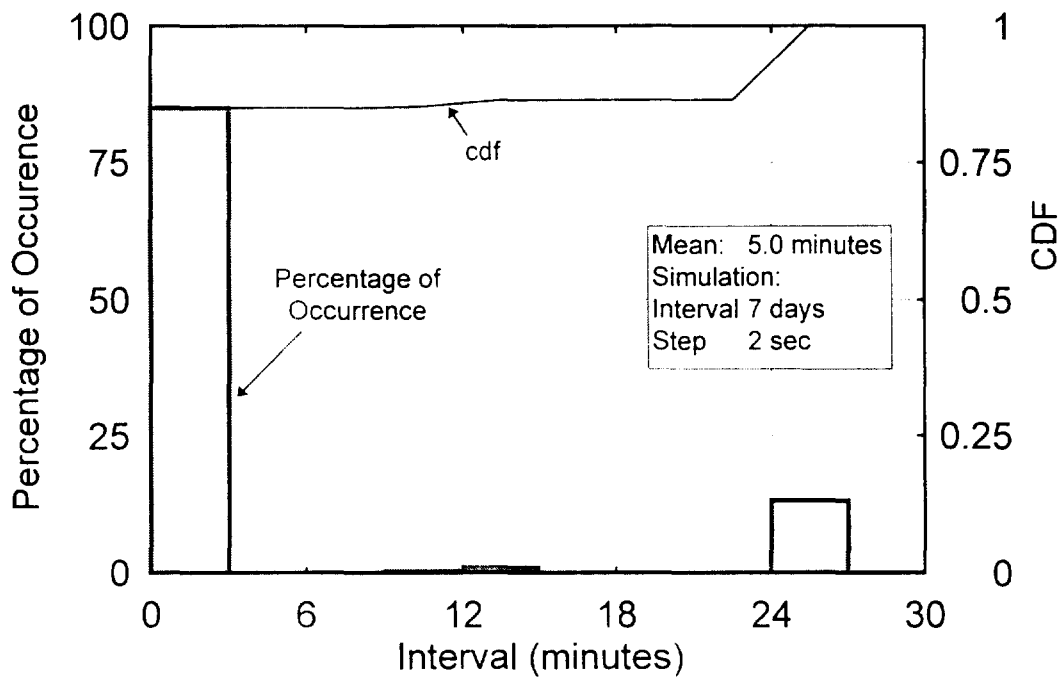

Figure 4.8 CASE 1, Latitude 25°, Interval Between Interference Events, Standard Earth Station .

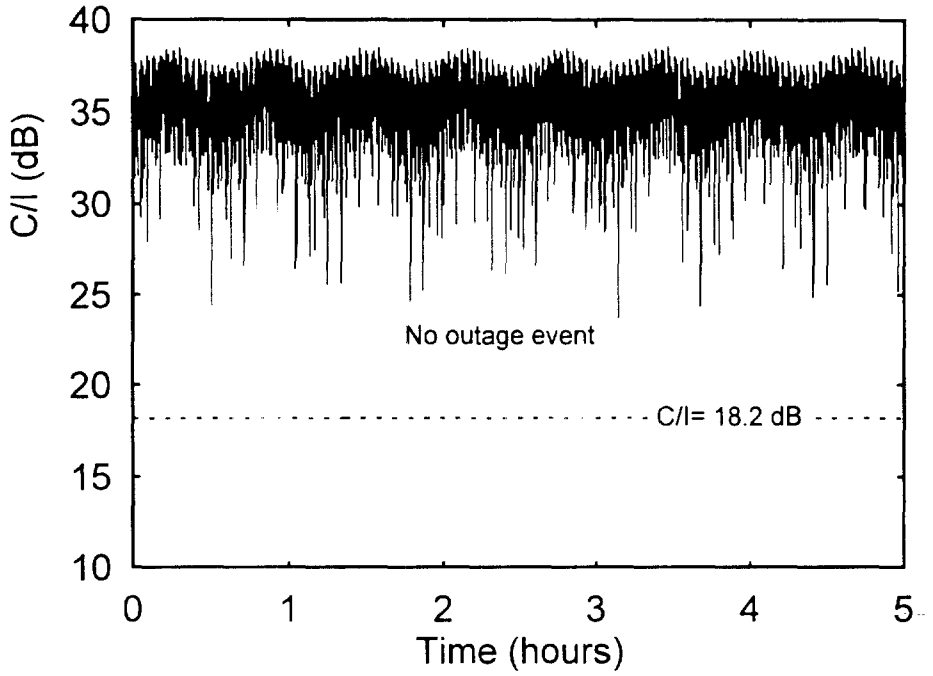

Figure 4.9 CASE 2, Latitude 40°, C/I Time History, Standard Earth Station .

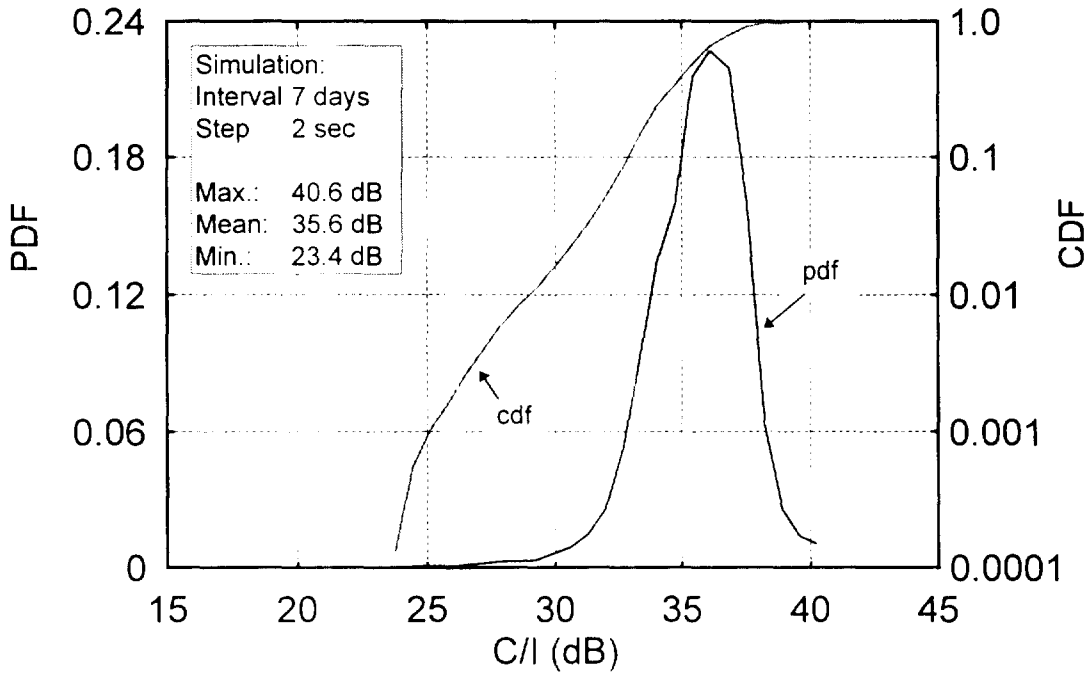

Figure 4.10 CASE 2, Latitude 40°, C/I Probability, Standard Earth Station .

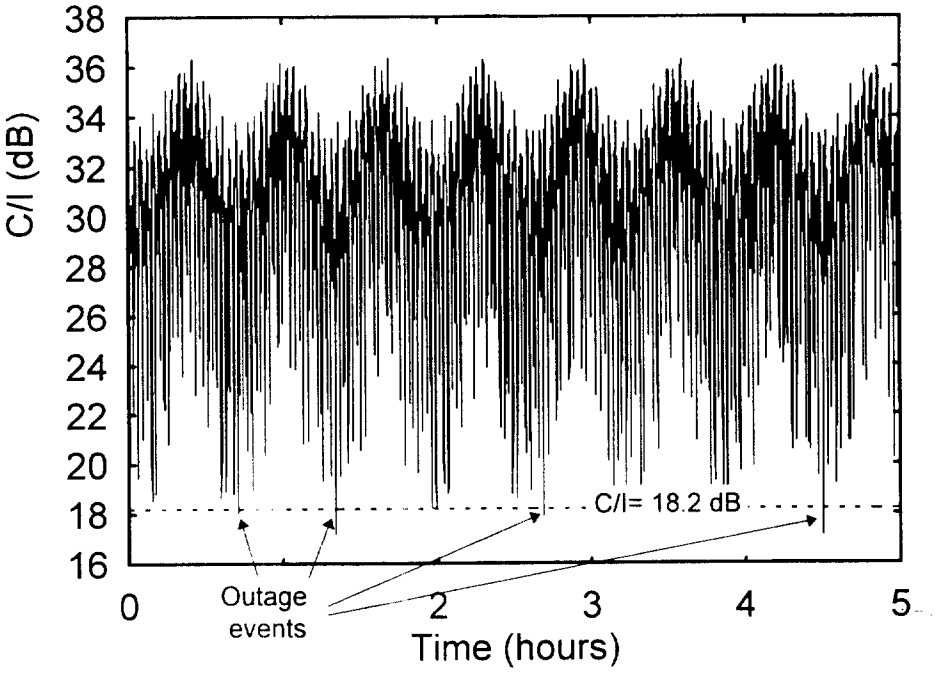

Figure 4.11 CASE 2, Latitude 25°, C/I Time History, Standard Earth Station .

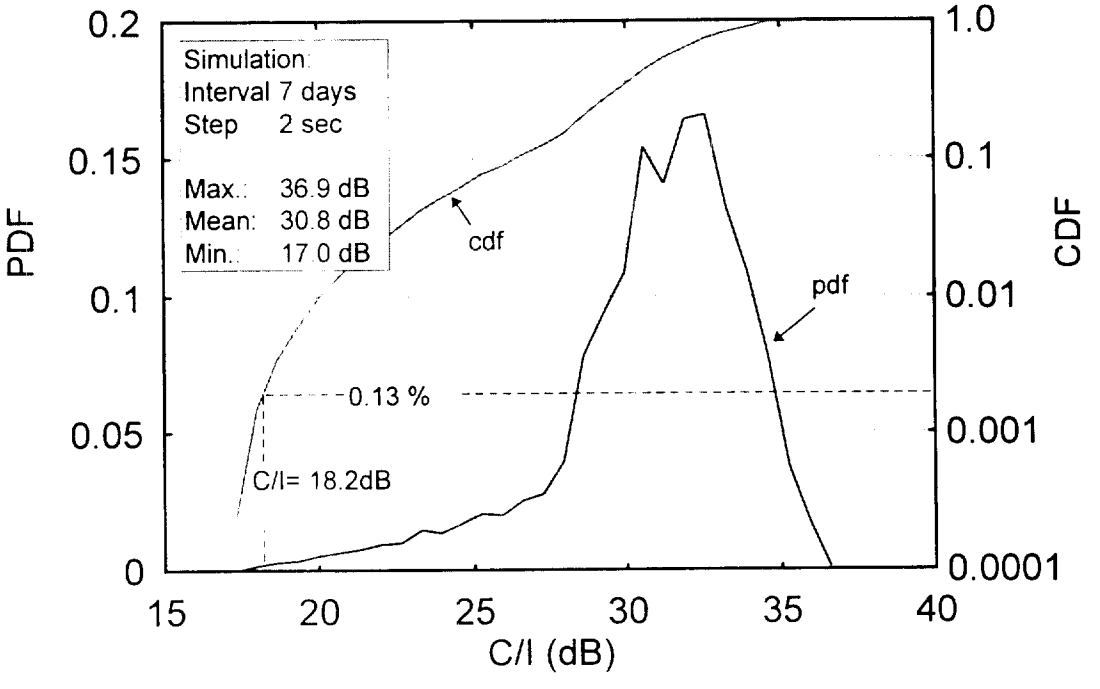

Figure 4.12 CASE 2, Latitude 25°, C/I Probability, Standard Earth Station .

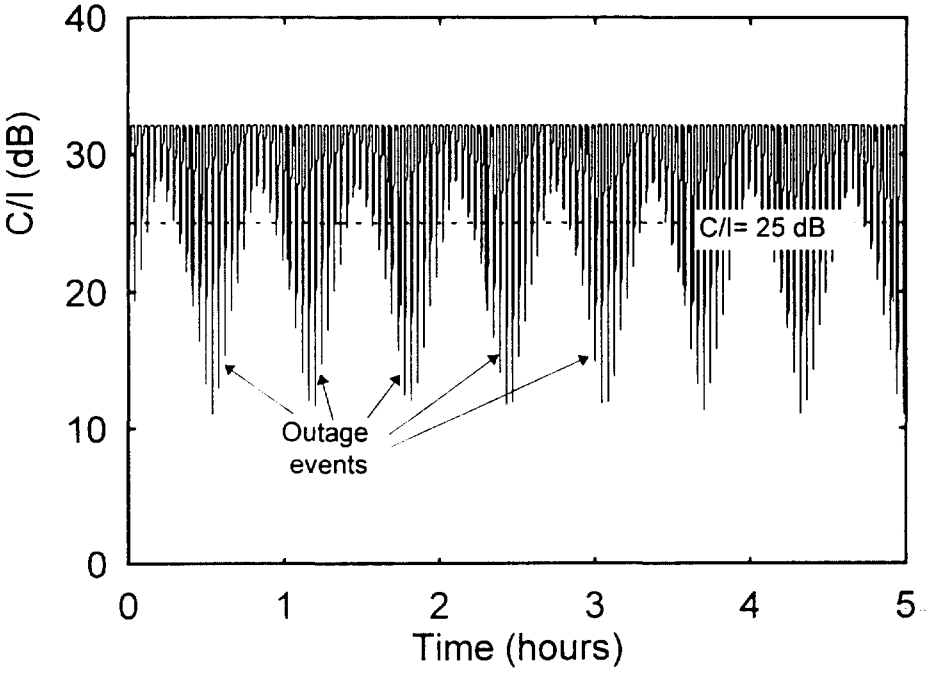

Figure 4.13 CASE 3, Latitude 40°, C/I Time History, Standard Earth Station .

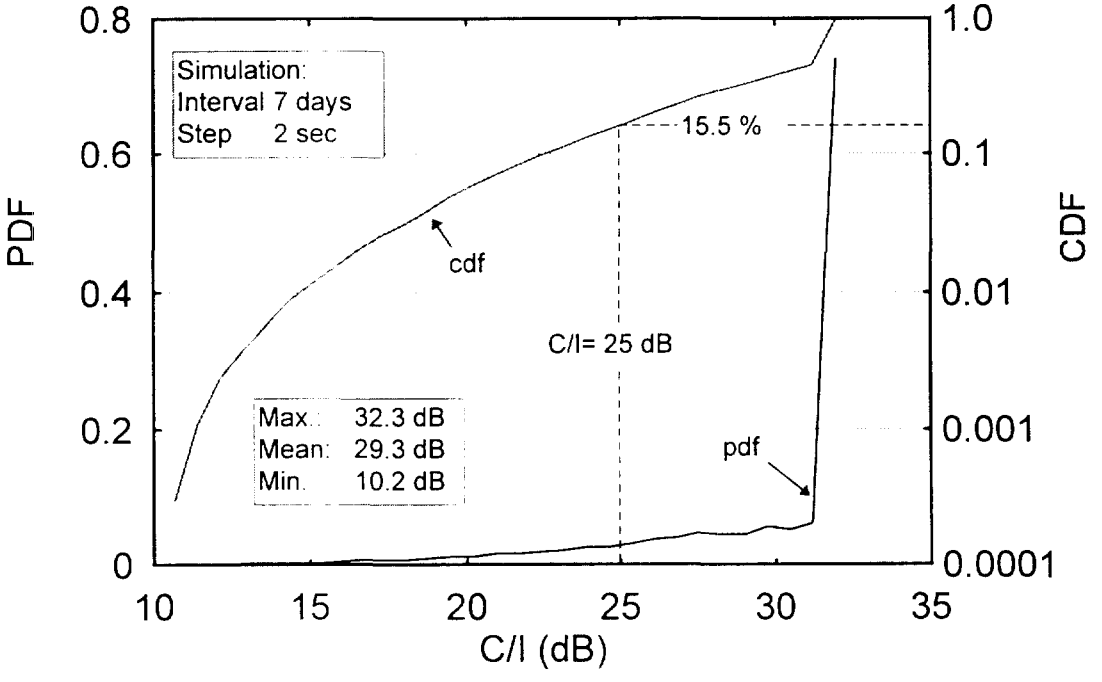

Figure 4.14 CASE 3, Latitude 40°, C/I Probability, Standard Earth Station .

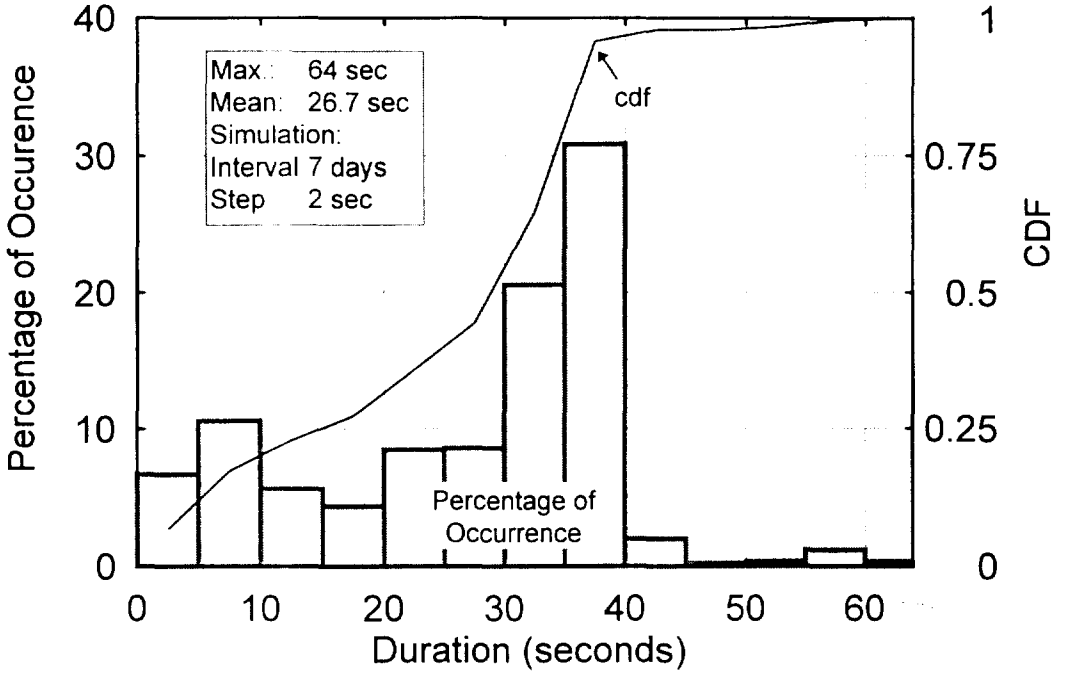

Figure 4.15 CASE 3, Latitude 40°, Interference Event Duration, Standard Earth Station .

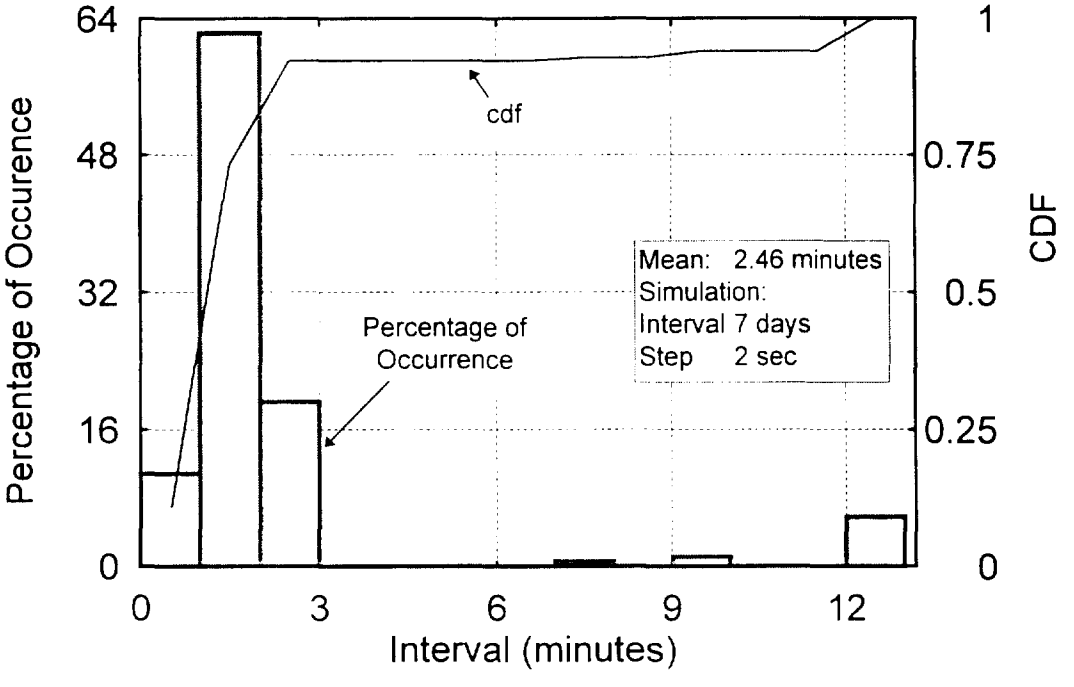

Figure 4.16 CASE 3, Latitude 40°, Interval Between Interference Events, Standard Earth Station .

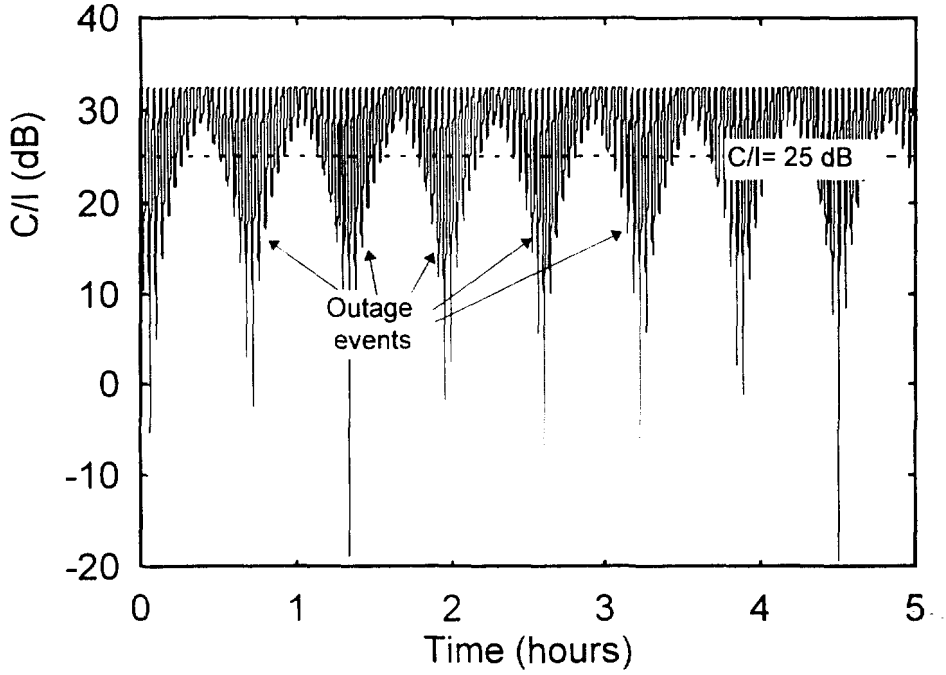

Figure 4.17 CASE 3, Latitude 25°, C/I Time History, Standard Earth Station .

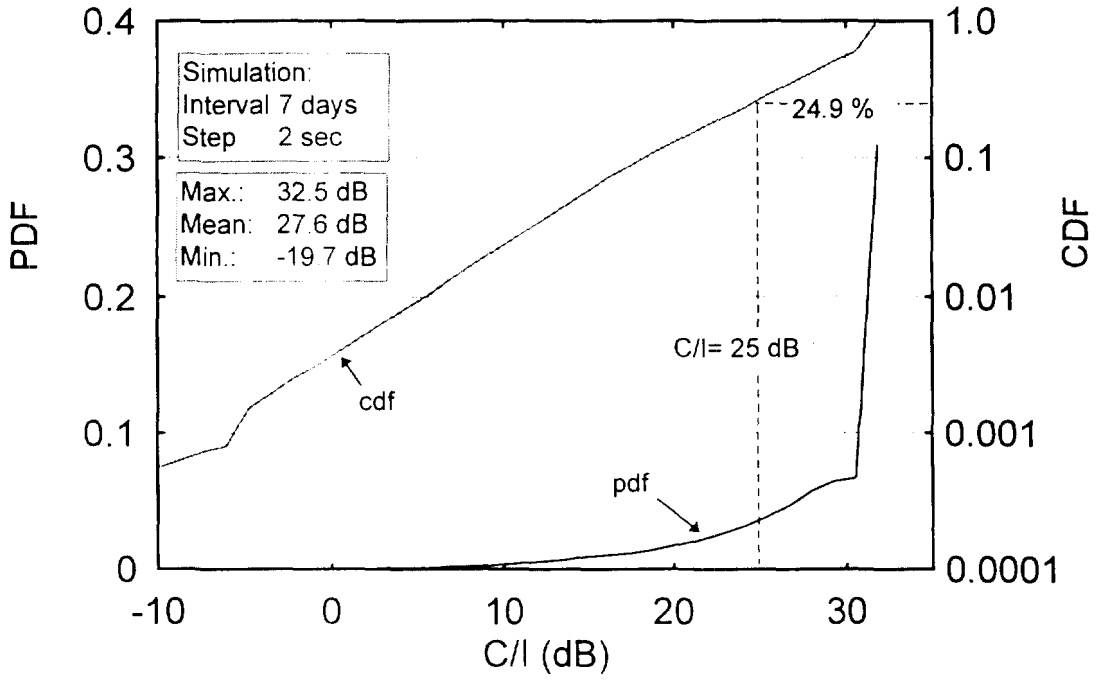

Figure 4.18 CASE 3, Latitude 25°, C/I Probability, Standard Earth Station .

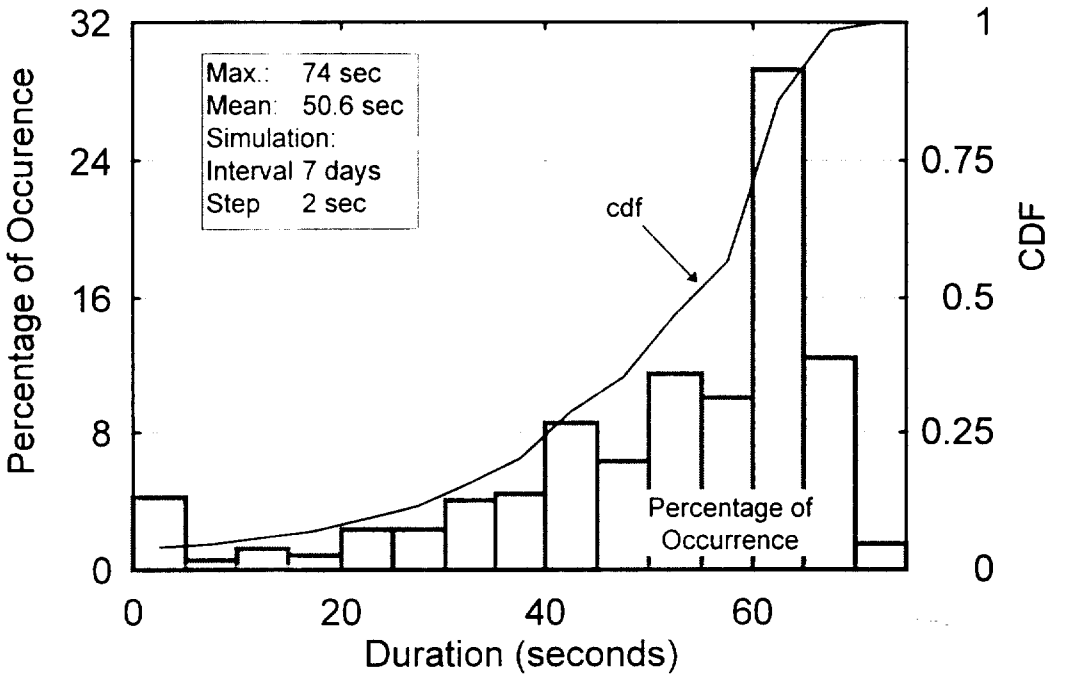

Figure 4.19 CASE 3, Latitude 25°, Interference Event Duration, Standard Earth Station .

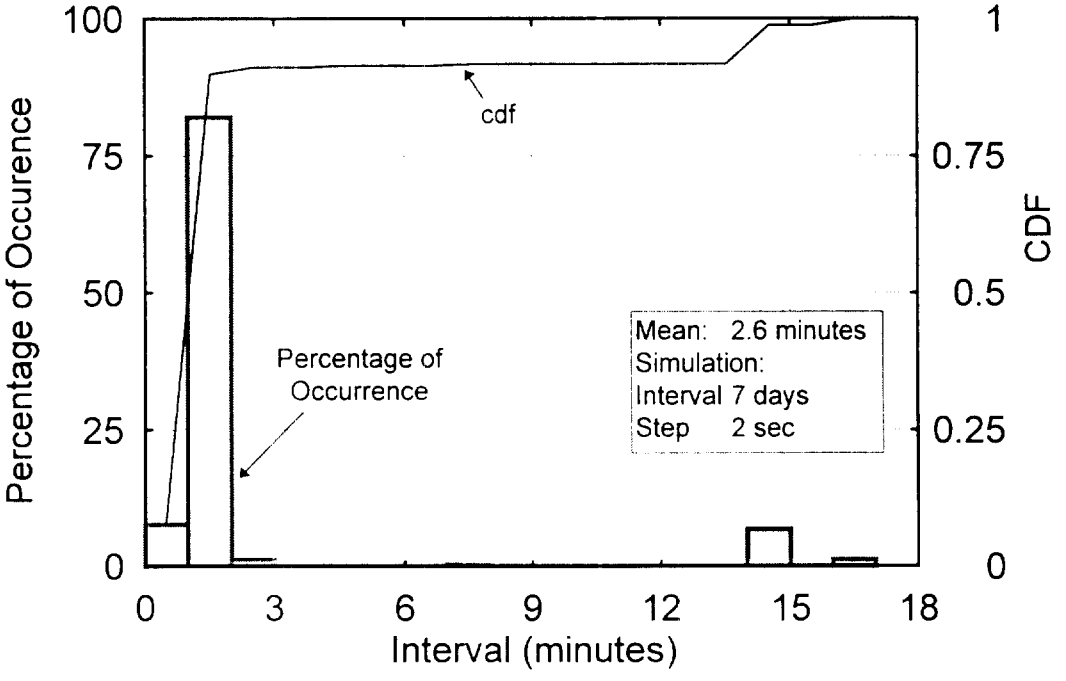

Figure 4.20 CASE 3, Latitude 25°, Interval Between Interference Events, Standard Earth Station .

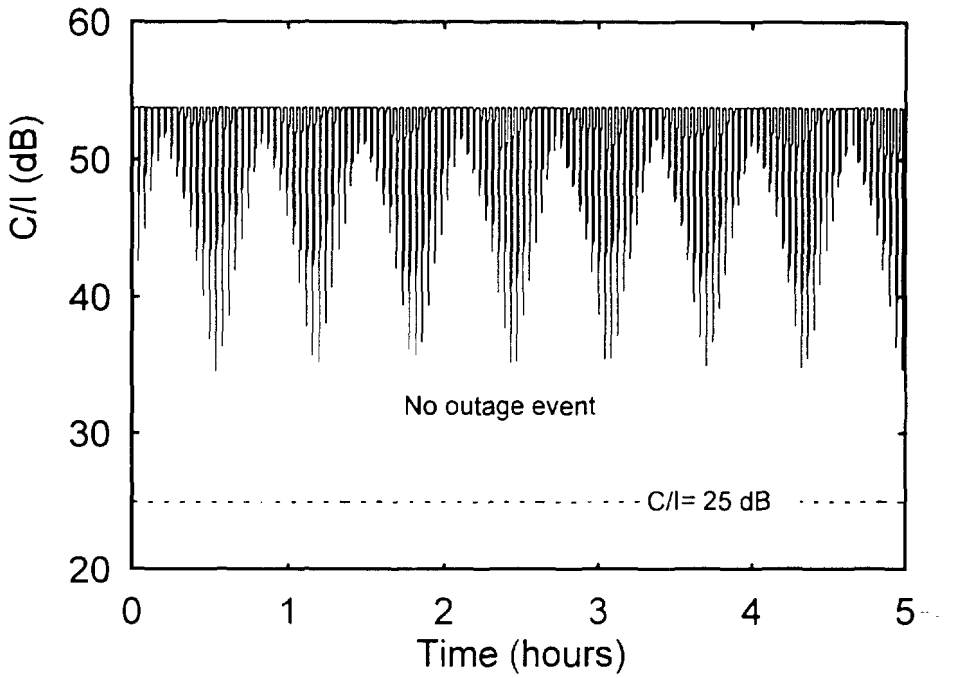

Figure 4.21 CASE 4, Latitude 40°, C/I Time History, Standard Earth Station .

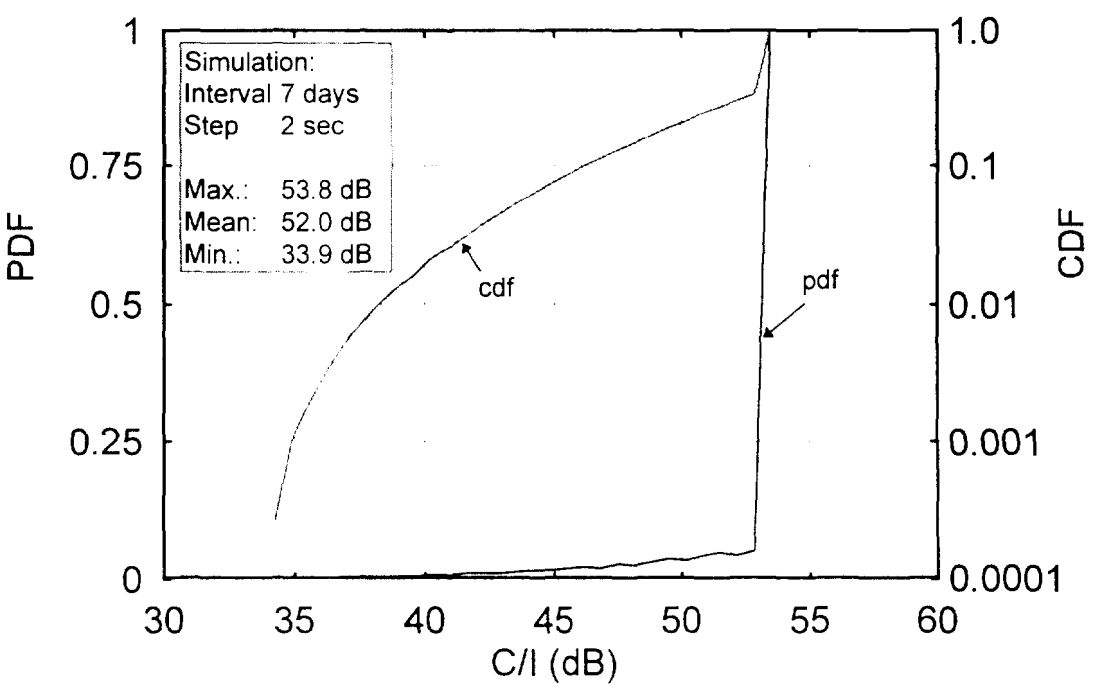

Figure 4.22 CASE 4, Latitude 40°, C/I Probability, Standard Earth Station .

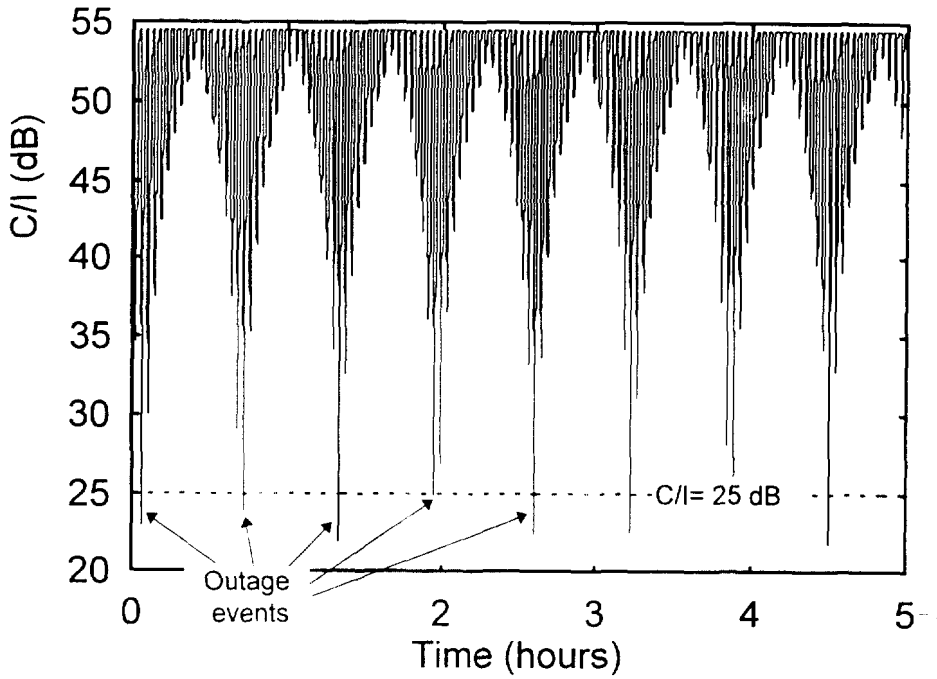

Figure 4.23 CASE 4, Latitude 25°, C/I Time History, Standard Earth Station .

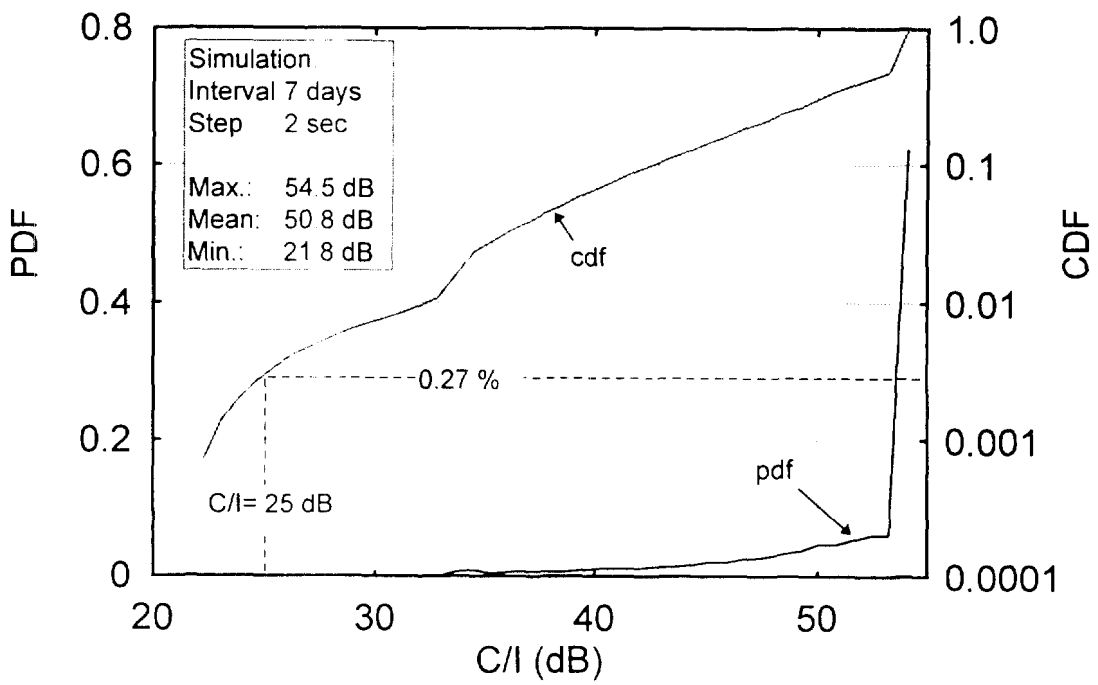

Figure 4.24 CASE 4. Latitude 25°, C/I Probability, Standard Earth Station .

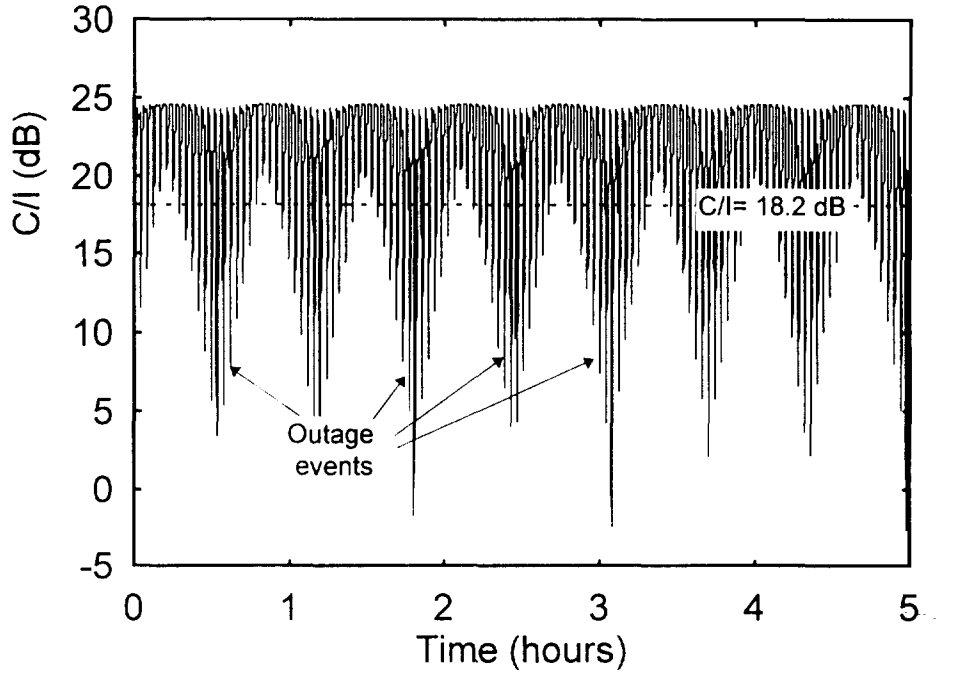

Figure 4.25 CASE 1, Latitude 40°, C/I Time History, Mobile Earth Station .

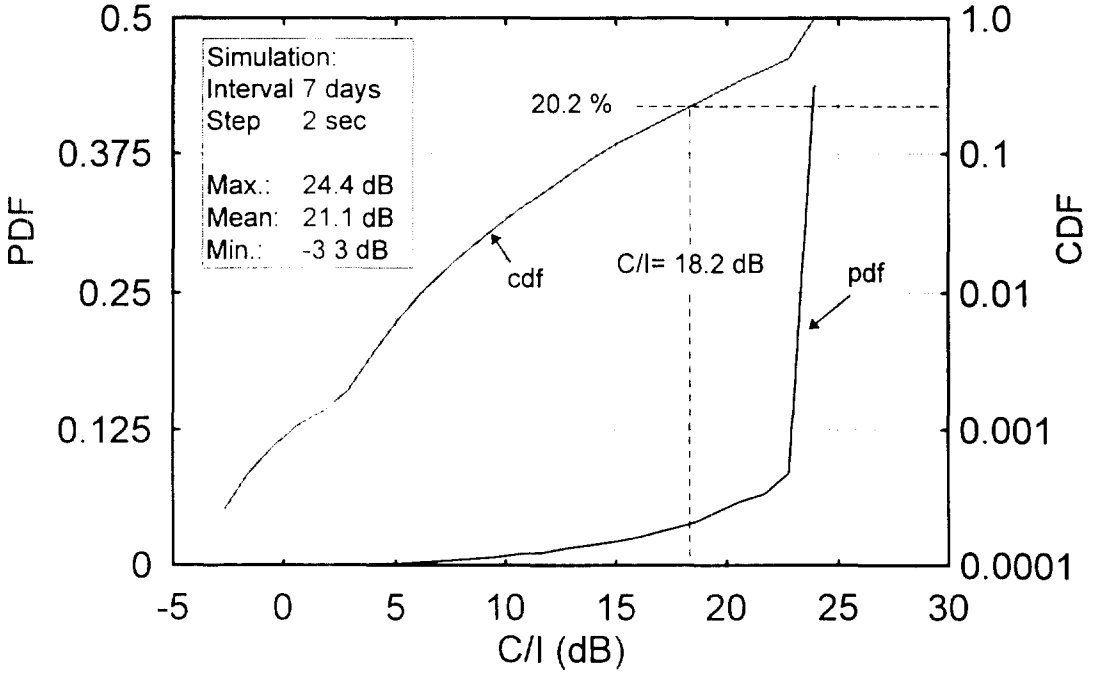

Figure 4.26 CASE 1, Latitude 40°, C/I Probability, Mobile Earth Station .